How does research funded by the Climate Program Office's MAPP program contribute to improved operational drought products?

Challenges/needs:

- Improved accuracy in the monitoring of ongoing drought conditions
- Better predictions to prepare for the development of drought conditions
- Further understanding of drought causes and behavior

Research to meet these needs:

- Accurate soil moisture data, useful for understanding monitoring, and for modeling drought
- Examination of computer model biases and understanding the role and influence of model input from the North American Land Data Assimilation System
- Utilizing data from satellites to improve drought modeling and understanding
- Harnessing model predictions of precipitation to improve indices that describe drought
- Utilizing multiple independent computer models to further improve seasonal and sub-seasonal drought prediction

Having the capacity to monitor droughts in near real time and to provide accurate drought prediction from weeks to seasons can greatly reduce the severity of social and economic damage caused by drought. Drought indices are used to monitor and predict many aspects of drought. For meteorological drought (lack of precipitation), the Standardized Precipitation Indices (SPI) have been recommended for use. Soil moisture (SM) levels are used as indicators of agricultural drought (lack of water impacting agricultural productivity). Runoff or streamflow anomalies are used to monitor hydrological drought (lack of water supply). The official U.S. Drought Monitor and the Drought Outlook are the leading operational national drought products, and are major contributors to the National Drought Information System (NIDIS). The Drought Monitor, Drought Outlook, and NIDIS integrate a diverse set of drought indicators from numerous sources. To support this integration, NOAA-funded research is targeted to improving drought monitoring and prediction systems, resulting in improvements in the U.S. Drought Monitor, Drought Outlook, and NIDIS capabilities. For example, NOAA's National Centers for Environmental Prediction (NCEP) Climate Prediction Center (CPC) issues several operational drought monitoring and prediction products, many of which are used in the preparation of the U.S. Drought Monitor and Drought Outlook as well as to inform NIDIS. NCEP's Climate Test Bed is a mechanism that aims at accelerating advances in NCEP's drought operational products. Advances in drought monitoring and prediction systems are sought as the result of MAPP grant-funded collaborative research projects involving academia, NOAA research laboratories and other research labs, as part of the Drought Task Force research efforts. A few examples of how NOAA MAPP research investments are delivering improved drought operational products are given below.

A. Advances in Drought Monitoring

a. Developing the North American Land Data Assimilation System for drought monitoring

SM percentiles are good indicators of agricultural drought. However, in contrast to the SPI used as an indicator of meteorological drought, there are few long-term, in-situ measurements useful to construct SM levels necessary to establish anomalous conditions. Earlier, the information on agricultural drought was provided by a simple "leaky bucket" model and the Palmer Drought Severity Index. Long-term multi-institution research investments (from the MAPP Program and its predecessors) have led to the development of the North American Land Data Assimilation System (NLDAS), an important step to provide Drought Monitor authors and

Drought Outlook forecasters more accurate and objective information on SM levels and runoff. The NLDAS products are now used operationally in the CPC monthly Drought Briefing to assess the current development of drought. These products are also used by the Drought Monitor authors and Drought Outlook forecasters for their operations.

Currently, both NCEP's Environmental Modeling Center (EMC) and the University of Washington (UW) run parallel drought monitoring systems over the continental U.S. based on the NLDAS. Because these two systems use different forcing and models, the comparison between the NLDAS from the EMC/NCEP and the UW system show that there are significant differences for the period 1979-2008, which point to remaining uncertainties. As an example, Figure 1 displays the monthly mean standardized SM anomalies and runoff index SRI6 averaged over the area 38-42^{o}N and 105-110^{o}W for the UW (green line) and NCEP (red line) ensemble means. For SM levels and runoff indices, differences are relatively small among different land surface models in the same system. However, the ensemble mean differences between the two systems are large and consistent over the western United States. Currently, NCEP CPC uses both systems for operational drought monitoring. Research is continuing on how to reduce uncertainties and further improve NLDAS for operational drought monitoring.

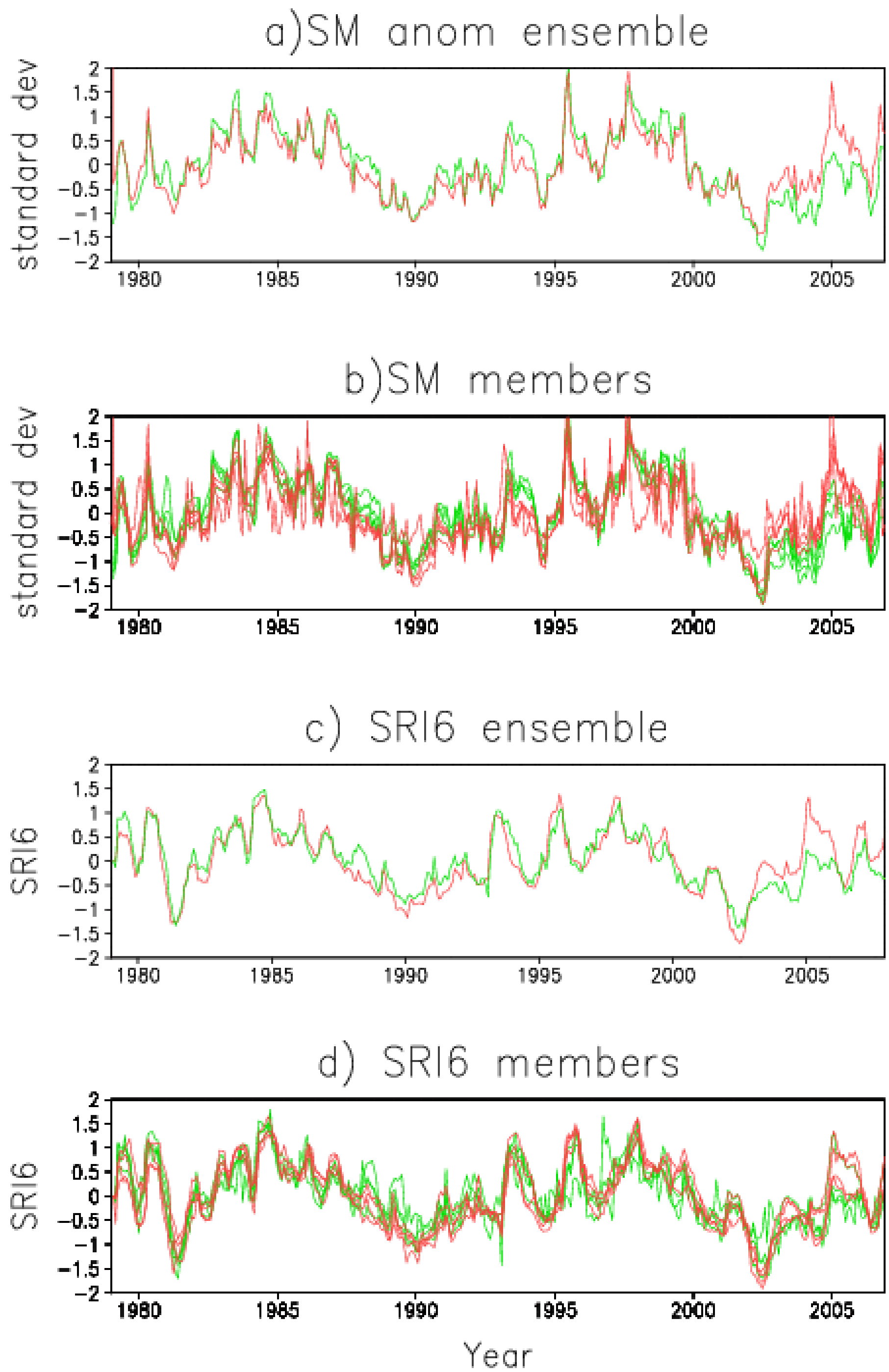

Figure 1: (a) Monthly mean standardized SM anomalies averaged over the area of (38-42^{o}N, 105-110^{o}W) for the UW (green line) and NCEP (red line) ensemble means; (b) same as (a), but for each individual member from the UW system (green lines) and the NCEP system (red lines); and (c)-(d) same as (a)-(b), but for SRI6

b. Advancing drought monitoring using remote sensed data

There is an urgent need for independent indicators to verify soil moisture and evaporation from the NLDAS because of remaining uncertainties in the NLDAS systems. An independent drought indicator can give water resource managers additional information to assess drought conditions. Satellite-derived drought indices have great potential to fulfill this need. Hence, much research has gone into developing methodologies to exploit remote-sensed data for drought monitoring with good payoffs. For example, thermal infrared imagery from the GOES satellite and a fully-automated inverse model of Atmosphere-Land Exchange (ALEXI) have been used to model hourly evapotranspiration (ET) and surface moisture stress over a 10-km resolution grid covering the contiguous United States. Validation studies for 2002-2004 over a range of land cover and climatic conditions indicate 10-15% accuracy in hourly ET. In May 2012, the USDA implemented the use of Evaporative Stress Index (ESI) in operations, an important recognition of its utility. The NCEP CPC also uses ESI, for drought monitoring. Figure 2 shows an example of the ESI, which can be compared with the soil moisture percentiles from the University of Washington NLDAS system. Both indicate drought over the Colorado basin and over the Ohio Valley. Research is ongoing to evaluate and understand differences between ESI and NLDAS systems, as well as to develop new methodologies to exploit a variety of remotely-sensed drought-relevant data for direct assimilation in NLDAS.

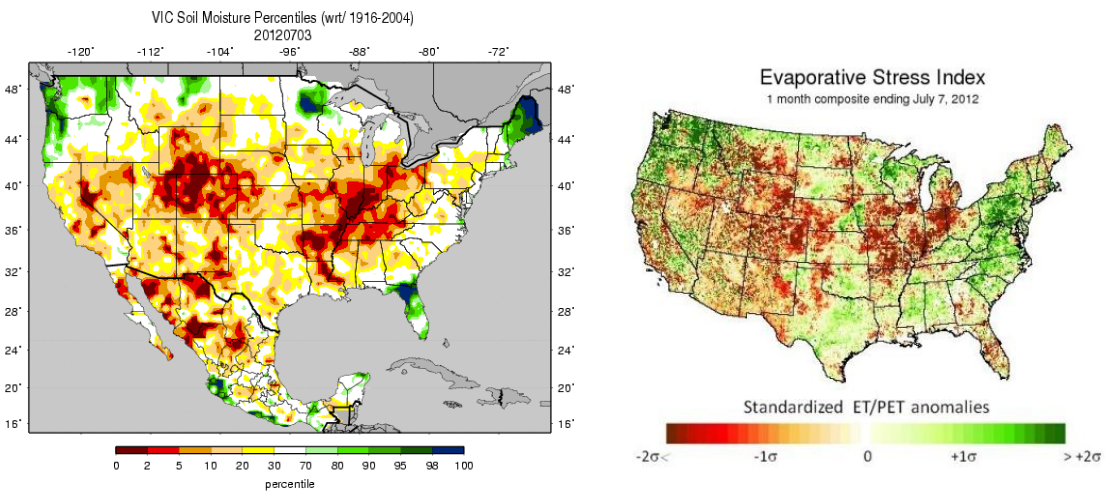

Figure 2: Soil moisture percentiles from the VIC model (University of Washington, left) and ESI (right), for June 2012. Contours are indicated by the color bar.

B. Drought Prediction

a. Drought prediction based on forecasted Standardized Precipitation Indices

Many international experts and representatives from national meteorological and hydrological services around the world have identified the SPI as a universal meteorological drought index for effective drought monitoring and climate risk management. A simple method has been developed at the NCEP CPC to operationally forecast three month and six month Standardized Precipitation Indices (SPIs) for the prediction of meteorological drought over the contiguous United States. The methodology is based on precipitation (P) seasonal forecasts from the NCEP Climate Forecast System, version 2 (CFSv2). Before predicting SPI, the P forecasts from the coarse resolution CFS global model are corrected for biases and downscaled to higher resolution, based on the probability distribution function method, to a regional grid of 50 km. The downscaled and bias-corrected CFSv2 P forecasts, out to 9 months, are appended to the P analyses to form an extended P data set. The SPIs are then calculated from this new time series. The skill is regionally and seasonally dependent, however overall, the six month SPI is skillful out to three or months.

NCEP CPC operationally implemented the SPI three month (SPI3) and six month (SPI6) forecasts in April 2011. Figure 3 shows the forecasts of SPI3 and SPI6 for July-September 2012. It shows that drought over the western interior states and the area from Mississippi basin to Illinois is likely to continue for two to three months.

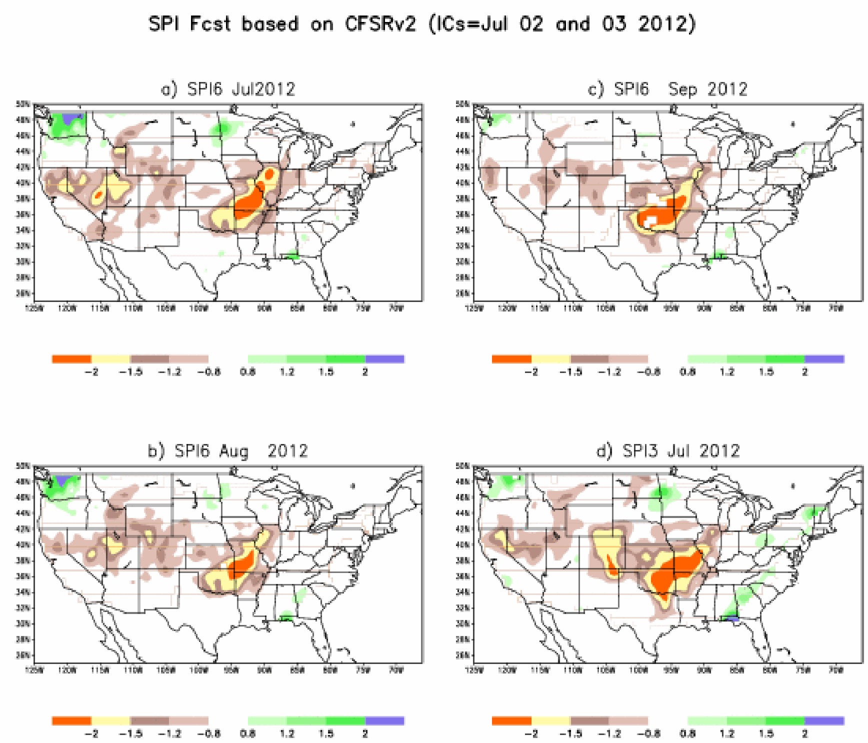

Figure 3: SPI forecasts initialized on July 2 and 3 2012 for (a) SPI6 one month lead, (b) two month lead, (c) three month lead, (d) SPI3 one-month lead. Contours are indicated by the color bar.

b. National Multi-Model Prediction Experiment for drought prediction.

Research has shown that climate prediction based on an ensemble of multiple climate models is generally more accurate that that from any single model. Hence, as part of its Climate Test Bed research efforts, NOAA's MAPP program has long invested in research to develop methodologies that optimally combine predictions for multiple models. These efforts have been accompanied by similarly important research efforts to fundamentally improve NOAA operational climate forecast system (manifested in the June 2010 release of the latest version of the Climate Forecast System).

More recently, the NOAA MAPP Program, in partnership with the Climate Test Bed, and with contributions from NSF, DOE, and NASA has initiated a research project, named the National Multi-Model Ensemble (NMME) Experiment to seek further improvements in intraseasonal to seasonal climate and drought prediction. The NMME project is utilizing an ensemble of leading national climate models in near-operational mode to provide climate forecasts for research purposes since August 2011. The NMME project includes a comprehensive research investigation regarding the optimal design and added value of this multi-model predictive system for climate and drought prediction. Figure 4 shows preliminary results from this multi-model system for precipitation and surface air temperature compared to results from single systems. In agreement with previous research, the NMME has predictive ability than that of any individual model. Although the NMME system is still an experiment, NCEP seasonal forecasters are already using its predictions as one of the inputs to producing official operational seasonal climate forecasts.

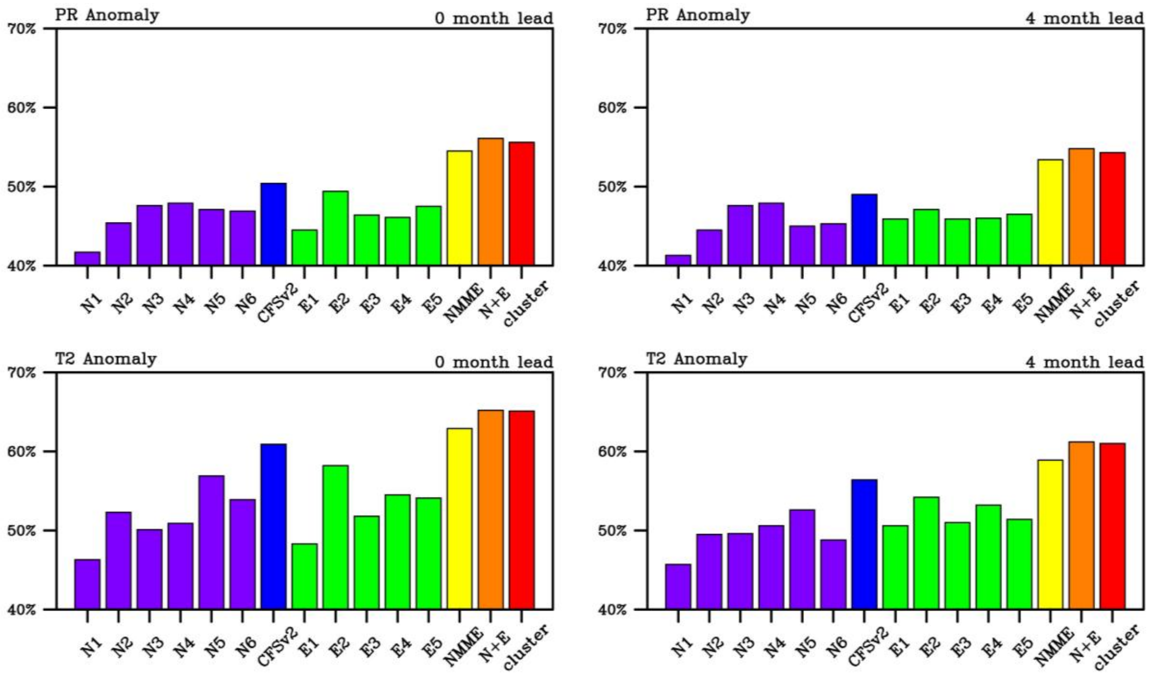

Figure 4: Percentages of skillful forecasts (Continuous Ranked Probability Skill Score: CRPSS>0) for seasonal mean precipitation and surface air temperature anomalies over global land areas. N1-N6 are individual models from NMME, and E1-E5 are from ENSEMBLES. (Yuan and Wood, submitted)

b) Multi Model ensemble forecasts of precipitation and surface temperature as tools for operational seasonal forecasts

A national multi-model ensemble (NMME) system has been developed with the support of the CTB /MAPP program. It is targeted for operational intra-seasonal to interannual (ISI) climate prediction. The NMME efforts are multi-institutional. The participating models are developed and verified independently increasing the likelihood that they have complementary or independent skill. It is this complementary skill that is the scientific basis for the multi-model approach. The institutions participated in the effort includes the NCEP, U-Miami/COLA/ESRL, NASA/GMAO and NOAA/GFDL. The phase 1 of the NMME which was completed in 2012 requires that the real-time ISI prediction system must be identical to the hindcast prediction system. The lead times us up to 9 months and the hindcast period is 30 years from 1981-2010. The required outputs include monthly mean global sea surface temperature, 2-meter temperature and precipitation. The data are available to users through the IRI. The CPC has been using the equally weighted ensemble mean SSTA and T2m and precipitation anomalies as forecast tools for the CPC official seasonal outlook. The phase 2 of the project will examine the best way to construct ensemble, and will develop hydroclimate forecasts for drought applications.